DOCUMENT RESUME

ED 148 599 SE 023 447

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TITLE Computer Simulated Experiments in Physics Teaching: Problems and Performance. A Review of the Problems with and the Literature on CSE in Physics Teaching with Suggestions for Future Research.
PUB DATE Dec 77
NOTE 51p.; Paper presented at the regional meeting of the National Science Teachers Association (Boston, Massachusetts, December 1977)

EDRS PRICE MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; *Computer Oriented Programs; Computers; Instruction; *Physics; *Research Reviews (Publications); Science Education; Secondary Education; *Secondary School Science

ABSTRACT

This document reviews problems associated with computer assisted instruction (CAI) in secondary level physics programs. Major problems are listed as availability, transportability, and validity. Programs for effective use of CAI are reviewed, future research in CAI is suggested, an extensive review of CAI research is provided, and a detailed list of references is included. (SL)

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COMPUTER SIMULATED EXPERIMENTS IN PHYSICS TEACHING: PROBLEMS AND PERFORMANCE

A Review of the Problems with and the Literature on CSE in Physics Teaching with Suggestions for Future Research

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A Paper Presented at
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Convention
Boston
December 2, 1977

SE 023 447

COMPUTER-SIMULATED EXPERIMENTS IN PHYSICS TEACHING:
PROBLEMS AND PERFORMANCE

ABSTRACT

Problems with computer use in computer-simulated experiments (CSE) and computer-assisted instruction (CAI) generally are detailed along with a review of the literature on the availability and validity of CSE in physics teaching. It is suggested that major problems of availability, transportability, and validity exist, that previous CSE efforts may have employed inappropriate models of computer use for programs to have been effective, that CSE is least effective when merely generating data or verbal explanations, that CSE is most effective when tied to sensory experiences and when programming is conversational, that vicarious experiences may effectively support CSE, and that CSE may be at least as effective as traditional laboratory instruction, and is more efficient. Future research is suggested regarding the use of CSE in large-group presentations and regarding the study (using the Flanders System of Interaction Analysis) of possible changes in classroom verbal interactions when CSE is introduced.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

Use of Computers in Science Education

Despite published expectations to the contrary (Bright, 1967; Gerard, 1967; Darnowski, 1968; Suppes, 1968a, 1969; Blackwell, 1972), computers have had little impact on secondary school science education. Certainly, the impact has not been as great as was earlier expected. Suppes (1969, p. 8) thought that by 1974 "between 200,000 and 800,000 students" would be receiving daily computer assisted instruction with the number rising to ten million by 1979. Bright (1967) predicted a major impact of computers in the classroom by 1977, and Blackwell (1972) felt that by 1980 the typical student would be spending part of each day with a computer.

While many schools have high-speed computing machinery accessible to them (Bukoski and Korotkin, 1976; Clivieri, 1976) and the hand-held calculator affords computing power to students in a way not possible befor, few schools incorporate such apparatus into the actual teaching of the subject matter of pre-college science (Weinstock and Wiley, 1977). Clivieri and Bukoski and Korotkin both estimated that even though half of the secondary schools in the country have access to computers the percentage of those schools utilizing computers in science courses had dropped from 21.1 percent in 1970 to 16.2 percent in 1975, with science

dropping from second to third place in terms of instructional usage. By comparison, mathematics accounted for 43.2 percent of instructional usage and computer science courses 21.7 percent (Bukoski and Korotkin, 1976, p. 16).

The overwhelming use of computers in education remains administrative (grade reporting, payroll, scheduling, etc.). This is particularly regrettable with respect to the teaching of physics since physics as a science distills experience almost exclusively into mathematical forms which are readily reformulatable as computer algorithms (Feynman et al., 1963, vol. 1, chap. 9; Greenspan, 1977).

While a number of ancillary difficulties have hampered the incorporation of computers in secondary school physics teaching (Suppes, 1967; Hall, 1971; Anastasio and Morgan, 1972; Fromer, 1973), it is argued here that the leading difficulty has been the selection of inappropriate models of computer use for secondary school science teaching, namely, the batch-processing and time-sharing models.

Batch-processing of computer programs on punched cards with the associated long turn-around times was early seen as being too cumbersome to substitute for other instructional techniques for communicating the subject matter of physics, although some use was made of this mode (Blum, 1969, 1971). The advent of time-sharing systems with real-time processing capabilities appeared to provide the immediacy and individualization computer users in physics education sought (Bork and Peckham, 1971).

Using time-sharing systems, a small number of large scale Computer Assisted Instruction (CAI) projects was begun (Kock, 1972). Two

of these are on-going major attempts at replacing teachers in a number of academic disciplines with terminals while a third has concentrated on physics alone. The first two are PLATO (Alpert and Bitzer, 1970; Bitzer, 1970, 1973; Smith and Sherwood, 1976) and TICCIT (Mitre Corporation, 1974; Alderman, 1975). The third is the Physics Computer Development Project (Bork, 1975b). These projects have gone forward for some years, but their impact has been negligible in terms of the number of secondary schools affected and, in most instances, their superiority as competitive alternatives to standard practices has yet to be rigorously validated (Alderman, 1973; Magidson, 1975). However, their future is presently viewed with an optimism similar to that reported earlier for computers in education generally (Douglas, 1976).

Time-sharing systems whose central processors are large, fixed installations servicing remote terminals either hard-wired or tied to telephone availability and using sophisticated CAI authoring languages have traditionally been used in a one-on-one relationship in which one terminal is used by one student with the program leading the student through a learning experience. The central processing unit (CPU) and multi-terminal requirements of such systems are still very costly both for installation and maintenance. Leasing of high grade data long-lines may further discourage use by increasing costs.

These high costs result in too few terminals per school for many students to be affected by them, and their unpredictable availability during fixed class schedules still further reduces their possible impact on larger groups. Even with the decrease in CPU costs, the remaining cost of terminals, connect charges, and particularly CAI

authoring expenses, make the widespread use of time-sharing for instruction economically prohibitive, except in special cases (Jamison, 1970; Hansen, 1970; Jones, 1972; Butman, 1973; Campbell and Jansson, 1974; Culp, 1975). Despite reports presenting favorable cost-effective projections for large-scale CAI systems such as PLATO and TICCIT (Statz, 1975; Douglas, 1976), an analytical study by Butman (1973, pp. 8-9) concluded :

> CAI systems which depend on a large central computer are most effective when serving a geographically compact population. From an economic standpoint, the compact population is least in need of CAI, for one almost invariably will choose the classroom approach when enough students to constitute a conventional class (25 or so) can be assembled. . . . A CAI system to serve [dispersed] populations should employ stand-alone terminals or at worst terminals which operate efficiently in small clusters. . . .

Hence, the arrival of small, mobile, self-contained intelligent terminals with stand-alone characteristics capable of driving a standard classroom TV monitor offers a third alternative to either batch-processing or time-sharing. Their flexibility in terms of location, reliability and low cost makes them particularly attractive (Bork, 1976).

But these smaller systems lack the necessary storage to present traditional CAI materials since such materials typically display large masses of information. The programs which do exist for the newer machines tend to be highly machine specific and to lack transportability to systems of different manufacture. This has been a long standing problem in the implementation of CAI generally (Nevison et al., 1974; Dunnagan, 1975).

Nevertheless, in the absence of the demonstrated superiority of the large-scale CAI project materials over competing options such as books, the low cost, mobility, ease of use, compactness and apparent

simplicity of the mini-computer driven terminal mean that schools will increasingly turn to intelligent terminals when computer purchases for instructional purposes are being made.

At the same time, these systems hold out possibilities for presenting the subject matter of physics in a way which benefits from the precision and generality of the conclusions of physics while avoiding in the teaching situation repetitive and distracting mathematical manipulations (Thomsen, 1977).

One such possibility lies in the use of a computer as an aide to the teacher in presenting physical phenomena through demonstration experiments. Such experiments are an integral part of physics teaching at the introductory level in lectures (Sutton, 1938; Meiners, 1972) but are sometimes forgone by instructors for varying reasons such as inadequate time, the danger which may be involved, or the absence of appropriate equipment or space.

Computer simulation of laboratory experiments in physics has been investigated as an alternative to traditional formats with, in some cases, the computer being used not merely to replace the laboratory apparatus but the teacher as well (see the review of the literature following).

A qualitatively different situation arises when the computer is used to aid actual classroom instruction under teacher direction. In that case, the teacher's participation is a critical element in reducing the information display overhead of the computer while letting the computer reduce the information processing time of the teacher.

Such a combination of teacher and computer should capitalize on

the strengths of both. The computer may be of the small, inexpensive, intelligent terminal type because the computer programs do not need to be monumental or access large data banks. The teacher can supply verbally the necessary supporting information and place the computer output in the verbal background essential to its interpretation and comprehension. At the same time, the computational speed and rapid display rate of a computer driven TV monitor would make possible the exploration of variations in physical parameters and the consequent alteration of dependent variables in a way not possible in the traditional format.

In addition, learning is more likely to be enhanced when students are actively engaged in the process, and such enhancement should result when it is the students who suggest the initial and subsequent changes in the parameters of the experiment performed by computer simulation. Then an information loop with feedback involving the students, the teacher, and the computer has been closed (figure 1).

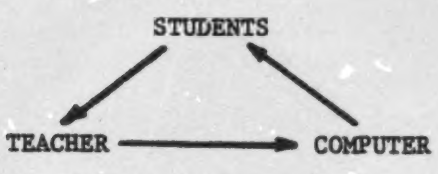

Figure 1. Feedback Information Loop in Interactive Computer Simulation Demonstration Experiments.

In such a situation, the teacher would present the physical situation and indicate the parameters normally variable. The students could

suggest changes in the variables, and the computer would calculate the consequences. The students might then suggest further changes based on a knowledge of the previous consequences until a generalization of the results could be achieved by induction and hypothesis testing.

The problem is that neither materials specifically designed for such computer use on a wide scale nor validation of the effectiveness of such materials exists.

Problems for Future Investigation

Even assuming that programs transportable from one computer system to another were available to physics teachers for computer simulated demonstration experiments, one must ask whether they should be used. Unless gains in achievement commensurate with the costs involved can be shown, there is little cause for implementing them. The question is direct -- will computer simulated demonstration experiments used interactively in a feedback loop produce enhanced learning as measured by student achievement?

The value of answering this question is practical. The purchase price of a small computer-driven TV display has fallen dramatically within the last ten years and can be expected to be in the range of the more expensive pieces of demonstration apparatus within a few years. But it has not, nor is it likely, to reach the point where its purchase, and the expense in terms of time and money necessary to program it, can be made without regard to its instructional effectiveness.

It is, therefore, important to know whether the use of such equipment in fact enhances learning.

In addition, will the supposed existence of the feedback loop

actually materialize? Will the involvement of the computer mean that the student-teacher verbal interactions in the lecture demonstration will undergo modifications? Will the substance, nature, or quantity of student or teacher talk be altered?

One would expect increased student participation to lead to more student initiated talk with the teacher simultaneously becoming less directive and more interrogatory.

But the presence of the computer may be inhibitory. It may lead to silences during input-output (I/O) operations and CPU processing which would actually reduce the number of verbal interactions. The restricted I/O format imposed by the programming may alter the quality of the student-teacher verbal interactions, leading them to satisfy the boundary conditions of the machine rather than the conversational needs of the participants in the classroom.

As the review of the literature following indicates, these questions remain unanswered. At the same time, they are among the more relevant questions that may be asked when observing the instructional process at a macroscopic, behavoral level. For these verbal patterns appear to be linked to the value systems which are a part of the cultural loading of instructional experiences (Medley, 1973).

The Analysis of Verbal Interaction in the Classroom

Numerous methods exist for the analysis of the classroom behavior of students and teachers (Simon and Boyer, 1967). Although nonverbal behavior is recognized as a highly important aspect of the classroom's social environment (Galloway, 1973), and methods have been sug-

gested for its observation and categorization (Amidon, 1971), it has received less attention than the analysis of verbal interactions which can be reported with a higher interobserver reliability (Flanders, 1967).

While a wide selection of techniques for observing and summarizing student-teacher verbal interactions exists (Sandefur and Bressler, 1971), it seems that there is little to distinguish them when one ignores superficial differences in their categorization schemes for verbal behavior and concentrates instead on identification of the actual factors and dimensions they report (Samph and White, 1973). The principal system for coding and recording such interactions is due to Flanders (1963, 1970, 1974).

The Flanders Interaction Analysis (FIA) system divides verbalizations in the classroom into ten categories (table 1). An observer records all changes in the classroom that constitute shifts from one category to another or, when no shifting is observed, at three second intervals, by sequentially recording the number assigned the appropriate category. Subsequently, the numbers are re-recorded as frequency counts in a ten by ten matrix (figure 2). The proper cell of the matrix is selected by using a number to determine the row and its successor to determine the column of the matrix element.

Column totals as well as totals for selected subsections of the matrix produce quantitative descriptions of the continuing and transitional verbal interactions and response patterns of the classroom. The percentage of time devoted to student talk, teacher talk, and silence or confusion as well as how much student talk follows teacher talk (and vice versa) can be calculated. Comparisons (computed as ratios) can be

TABLE 1

FLANDERS INTERACTION ANALYSIS (FIA) SYSTEM CATEGORIES[1]

TEACHER TALK	INDIRECT INFLUENCE	1. ACCEPTS FEELING: accepts and clarifies the feeling tone of the students in a nonthreatening manner. Feelings may be positive or negative. Predicting and recalling feelings are included. 2. PRAISES OR ENCOURAGES: praises or encourages student action or behavior. Jokes that release tension, not at the expense of another individual, nodding head or saying "uh huh?" or "go on" are included. 3. ACCEPTS OR USES IDEAS OF STUDENT: clarifying, building, or developing ideas or suggestions by a student. As teacher brings more of his own ideas into play, shift to category five. 4. ASKS QUESTIONS: asking a question about content or procedure with the intent that a student answer.
	DIRECT INFLUENCE	5. LECTURES: giving facts or opinions about content or procedure; expressing his own idea; asking rhetorical questions. 6. GIVES DIRECTIONS: directions, commands, or orders with which a student is expected to comply. 7. CRITICIZES OR JUSTIFIES AUTHORITY: statements, intended to change student behavior from nonacceptable to acceptable pattern; bawling someone out; stating why the teacher is doing what he is doing, extreme self-reference.
STUDENT TALK		8. STUDENT TALK-RESPONSE: talk by students in response to teacher. Teacher initiates the contact or solicits student statement. 9. STUDENT TALK-INITIATION: talk by students, which they initiate. If "calling on" student is only to indicate who may talk next, observer must decide whether student wanted to talk. If he did, use this category.
		10. SILENCE OR CONFUSION: pauses, short periods of silence, and periods of confusion in which communication cannot be understood by the observer.

[1]There is no scale implied by the numbers. Each number is classificatory.

SOURCE: E. Amidon and N. Flanders. Interaction analysis as a feedback system. In Interaction Analysis: Theory, Research and Application edited by E. J. Amidon and J. B. Hough. (Reading, Massachusetts: Addison-Wesley Publishing Company, 1967), p. 125.

Subsequent Event

Initial Event

	1	2	3	4	5	6	7	8	9	10	Total
1											
2		E									
3											
4					F						
5											
6											
7											
8											
9											
10											
Total											
%											

K spans rows 2–9, column 8
L spans rows 6–9, column 8
G spans rows 6–7, columns 6–7
I spans rows 8–9, column 2
J spans rows 8–9, column 6
H spans rows 8–9, column 8
A spans Total row, columns 2–3
B spans Total row, columns 6–7
C spans Total row, columns 8–9
D spans Total row, column 10

Area A: Indirect teacher talk.
Area B: Direct teacher talk.
Area C: Student talk.
Area D: Silence or confusion.
Area E: Acceptance of feelings, offering praise, using student ideas (by teacher).
Area F: Indicates concentration of interactions on subject-matter content of class.
Area G: Teacher gives criticism or offers self-justification.
Area H: Indicates either long student responses or student-to-student conversation.
Area I: Teacher responding to student talk with indirect influence.
Area J: Teacher responding to student talk with direct influence.
Area K: Student responding to teacher's indirect influence.
Area L: Student responding to teacher's direct influence.

Figure 2. The FIA Category Matrix with its Subsections.

made between indirect and direct teaching methods (the ID ratio[1]) and between those methods when the teacher is not concentrating on subject matter presentation but on motivation of the students and control of the classroom situation (the id ratio[2]). In addition, a ratio[3] for direct-student talk and a ratio[4] for sustained classroom verbal behavior to transitional behavior can be established.

Comparative studies of the percentages and ratios given show significant differences between grade levels and between content areas regardless of the teachers employed as well as distinguishing between highly rated and poorly rated teachers within a grade or subject area (Amidon and Hough, 1967).

For instance, in science teaching, while the exact relationship between classroom interaction and science teacher effectiveness is unclear, the FIA system has been useful in identifying certain aspects of teacher effectiveness (Evans, 1970) although conflicting results have been reported. Thus, Pankratz (1967) was able to distinguish between highly rated and poorly rated physics teachers using Hough's modification of FIA while Gold (1966), using the same modified system, was unable to produce similar results with biology teachers.

Interaction analysis as a feedback system has been widely em-

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[1]ID ratio = totals of columns 1-4 divided by the totals of columns 5-7 of figure 2.

[2]id ratio = totals of columns 1-3 divided by the totals of columns 6-7 of figure 2.

[3]Direct-student talk ratio = totals of columns 5-7 divided by totals of columns 8-9.

[4]The ratio of the total tallies in the steady state cells (M_{ij} where i=j) to the total tallies in transitional cells (M_{ij} where $i \neq j$).

ployed in micro-teaching and teacher training both to identify, for later modification or improvement, the verbal habits of teachers and to trace changes in such habits over time (Amidon and Hough, 1967; Amidon and Hunter, 1967).

FIA and its derivatives do not appear to have been used to measure changes in verbal behavior following the introduction of a high-technology instructional innovation into the classroom, such as a computer, though it is reasonable to believe that the introduction of such an innovation must alter the overt behavior of the classroom if it is to impact the effectiveness or efficiency of in-class instruction. At a minimum, the ratios of student-talk to teacher-talk should change if the presence of the innovation is itself expected to be a critical element in the establishment of an information feedback loop.

Other changes might occur in the amount of silence (while the computer is displaying material), in shifts from lecturing to questioning (as the teacher prods students to suggest input values), in changes in the use of teacher praise (as the computer provides some corrective reinforcement), or in the amount of acceptance or criticism of student ideas (as the teacher turns them over to the more impersonal judgement of "the facts", i.e. the calculated consequences of the students' suggestions).

IA offers the possibility of investigating quantitatively predicted changes in the instructional process following the introduction of Computer Simulated Experimentation (CSE) into the classroom and suggests hypotheses concerning the direction of such change.

CHAPTER II

REVIEW OF RELATED RESEARCH

The Effectiveness of CAI

Since the early work in drill-and-practice in elementary school arithmetic (Suppes et al., 1966, 1968b), the instructional effectiveness of computer assisted instruction (CAI) both in absolute and relative terms has been variously reported. The assumptions implicit in the use of CAI have been argued to be unsound (Barrett, 1968; Oettinger, 1969) although these criticisms have been said to be unfounded (Weinstock, 1973). The effectiveness of CAI drill-and-practice has found support in a number of reported studies (Suppes and Morningstar, 1968; Vinsonhaler, 1972) as have additional uses of CAI in other areas (Hedges, 1973).

Reviews of the literature on the effectiveness of CAI generally have been undertaken by Bundy (1968), Fletcher et al. (1972), Jamison et al. (1974), Taylor et al. (1974) and Edwards et al. (1974, 1975).

Bundy (1968, p. 425) concluded that "students seem to learn at least as well with CAI as with conventional classroom instruction. . . . CAI can provide learning and retention at least equivalent to conventional techniques in the same amount of time."

Fletcher at al. (1972, p. 1) concluded that "we have found strong and consistent achievement gains by students when they are given CAI over a reasonable fraction of a school year."

Jamison et al. (1974, p. 55) concluded after comparing the ef-

fectiveness of CAI, programmed instruction, and television with traditional instruction that "CAI is about as effective as TI [traditional instruction] when used as a replacement. It may also result in substantial savings of student time in some cases."

Taylor et al. (1974) reviewed CAI research under the headings of four usage modes, namely, drill-and-practice, problem solving, tutorial and simulation, and concluded that:

1. most CAI programs have never been evaluated for effectiveness

2. when evaluated, CAI is found to be effective

3. tutorial and drill-and-practice are more effective than problem solving and simulation

4. CAI is more efficient than traditional instruction

5. retention is higher for traditional instruction

6. when supplementing traditional instruction CAI is as effective as any other form of individualized instruction

7. CAI works best with low ability students

8. in the absence of equipment malfunction, CAI generates student and teacher enthusiasm.

Edwards et al. (1974, 1975) repeats Taylor's review.

CAI successes were early reported in science teaching at the undergraduate level. Statistically significant differences favoring CAI (p not reported) in chemistry achievement when compared with control groups receiving traditional instruction were observed by Culp (1971). In physics, CAI use improved examination performance of first-year physics students ($p < 0.01$) when compared with a control group (Kromhout et

al., 1969) while similar effects in undergraduate chemistry were observed by Castleberry and Lagowski (1970) and discussed (Castleberry, Montague and Lagowski, 1970).

A large CAI physics education project was conducted by Hansen et al. (1968) in which CAI was integrated with a highly individualized multi-media approach to first-year undergraduate physics instruction and compared with traditional lecture-recitation sections. Development efforts continued for three years and a complex research study was undertaken to determine instructional and cost effectiveness as well as ancillary studies on student personality characteristics, individual differences, and performance predictors.

Although volunteers were used in the experimental groups, no significant differences in student achievement were observed based either on final grade achievement or performance on the traditional examination. With respect to individual differences, however, Hansen et al. concluded (p. 131):

> . . . the more striking results suggest that generally speaking persons who are slightly less mature in their academic style, who are more sensitive and esthetic, and who are not scientifically oriented, have a higher probability of success if they take their physics instruction via the CAI/media course. On the other hand, persons who are somewhat autonomous, independent thinkers, who have scientific interests and who have a mature scientifically-oriented method of inquiry will have a greater chance of success if they take the traditional mode of physics instruction.

Problems in CAI Use

Even with the reported successes of CAI, its use is not widespread. Weinstock and Wiley (1977, p. 190) have concluded that "many effective computer-based educational aides have been developed in the

past, but their overall impact has been slight." They identified shortages of terminals, the lack of computer oriented textbooks in subject matter fields, and the absence of transportability of computer programs from one computer system to another as the principal causes underlying the non-use of computers in instruction.

The magnitude of the transportability problem can be gauged from the fact that of twenty-seven representative computer assisted instruction projects in physics reported in 1969 twenty different computer systems were employed with seventeen different computer languages. These included FORTRAN, BASIC, PL/1, JOSS, ISIS, TELCOMP, LOGO, STRINGCOMP, COURSEWRITER I and II, TOC, ASSEMBLY, DECAL, ELIZA, APL and an unidentified language called "Special" (Schwarz et al., 1969).

Additional difficulties, including long development times (Dowling, 1972), local conditions (Fulton, 1973), or user perceptions (Lower, 1973) may retard the introduction of computers in science education. Suppes (1967) identified machine reliability, neglect of content due to concern over programming, user boredom and cost as impediments while Fromer (1973) stressed the problems of authoring CAI material.

Blum and Bork (1969) report that from ten to two hundred hours of programming time are required to produce one hour of computer terminal CAI instruction. Despite recent attempts at reducing that preparation time, it remains essentially unchanged, and the cost of $5280 per terminal hour for CAI development, field validation and revision reported by Hansen et al. (1968) may still remain a valid order of magnitude estimate.

In general, however, Anastasio and Morgan (1972, p. 11) concluded

that "the lack of good, readily available computer-based educational materials [and] the fact that there are few examples of effective CAI" were the major impediments to widespread use. At the same time, they identified simulation as the most promising form of CAI and called for its extensive development.

Computer Simulated Experiments

The justifications for computer simulated experiments in teaching were given by Braun and Visich when they were directors of the two Huntington Computer Projects which produced the most widely distributed CSE materials in science teaching during the early seventies (Braun, 1970; Visich and Braun, 1974). Visich and Braun argued (1974, p. 5) that CSE is justified as the primary learning experience when:

> 1) The necessary equipment is not available because of expense, or is too complex or delicate to permit students to use it (e.g., in high-energy physics).
> 2) The sample size available in the real world is too small to permit generalizations . . .
> 3) The experimental technique is difficult and must be developed over an extended period (e.g., in experiments in genetics, and in titration).
> 4) There are serious dangers to the student (e.g., where radiation and high temperature are involved, where there may be explosive mixtures of gases, or where highly toxic materials are required).
> 5) The time scale is too short or too long to permit the student to make observations (e.g., the study of the dynamics of population, or the run-a-way (sic) of a nuclear reactor . . .).
> 6) The opportunity to experiment directly is not available (e.g., in studies of ecological, economic, political, or social systems, or in studies of human genetics, or spread of disease).
> 7) When it is desirable to measure variables which are difficult to access (e.g., the tension on a pendulum string, or the differential effects of the gravitational forces of the earth and the moon on an orbiting satellite).
> 8) When measurement and other noise obscures the important phenomena (in the computer, we can create a world in which there is no noise and in which instruments are perfect, and then show the student how noise and imperfect instruments obscure the data of interest).
> 9) There are times when it is useful to under score the significance

of natural laws by comparing their results with other laws (e.g., study of non-inverse-square-law gravitational systems, or non-Mendelian genetics).

Liao (1972) presented similar reasons behind the intensive use of an analog computer in the secondary school science course called The Man-Made World which originated from the Engineering Concepts Curriculum Project (ECCP).

With respect to CSE use, Showalter (1970) identified eleven potential benefits for science education among which were inquiry skills development, individualization, learning efficiency, reduced software development costs over tutorial CAI, and increased student creativity.

Yet the major portion of the literature of CSE consists of journalistic announcements of sample CSE applications in authors' courses. Among these announcements are applications in chemistry (Griswold, 1968; Schwendeman, 1968; Smith, 1970; Rodewald et al., 1970; Craig et al., 1971), biology (Norberg, 1975), earth science (Fox, 1969) and physics.

The physics literature contains statements of encouragement and anticipated use (Shirer, 1965 ; Bork, 1968; Blum and Bork, 1970; Hearn and Reid, 1970; Chesley, 1971; Martin, 1972; Yu, 1974; Bork, 1975a; Dowling, 1975) as well as specific illustrations of the employment of individual programs. These programs can be found in the areas of mechanics (Wilkins and Klopfenstein, 1966; Bork and Luehrmann, 1968; Haddad, 1968; Baltz and Machlup, 1971; Jirgal, 1972; Peckham, 1972b; Greenslade, 1973; Lunetta, 1974; Ostrander, 1975), astronomy (Messina, 1972), optics (Grossberg, 1969; Merrill, 1971; Peckham, 1972a; Finn, 1973; Inman et al., 1975), statistical mechanics (Anger and Prescott, 1970; Peckham, 1972d), relativity (Hickey, 1975), quantum mechanics (Merrill, 1973),

laboratory data analysis (Bron, 1972) and environmental physics (Evans, 1976).

General compilations of programs are also available which cross a number of the subfields of physics (Blum, 1969; Lindsay, 1969; Braun, 1971, 1972; Merrill, 1972, 1976; Robson, 1971; Peckham, 1972, 1975; Ehrlich, 1973; Jones, 1973). A major but not exhaustive bibliographical listing of computers in physics teaching through April of 1975 (Cox, 1975) lists some seventy books, one hundred forty-five journal articles, and twenty-five miscellaneous publications covering twenty-two areas of undergraduate physics instruction. Almost all of these computer uses are unevaluated by other than author observation or user judgement.

Review of Research on CSE

Boblick (1972a, 1972b) reported that CSE in a tutorial mode in chemistry and physics could produce achievement gains among the CSE group which were higher than that of control groups.

In one major study of CSE involving physics students in five similar Northeastern high schools (Lunetta, 1972, 1974; Lunetta and Blick, 1973), a series of four computer simulated experiments were prepared which allowed students to generate and graph at will data dealing with force and motion (Newton's second law). CSE was associated with film loops to make the simulation more vivid. The effect of this treatment (Group I) was compared with another treatment (Group II) in which students were provided with already filled out data tables and problem sheets. Group II viewed the film loops but did not make use of a computer. A control group (Group III) performed traditional laboratory ex-

periments with PSSC momentum carts in order to obtain their data. Group I was not permitted access to a human teacher except upon computer initiated request. The remaining groups were permitted free access to the instructor. Teachers were different for the three groups, and, while the film loops were seen by Groups I and II, they were not seen by the control group.

Using objective-based criterion-referenced evaluation instruments in a pretest (KR_{20} = 0.85), treatment, posttest (KR_{20} = 0.78) with attitude survey plus repeated posttest in a quasi-experimental design (Campbell and Stanley, 1963), Lunetta investigated achievement, achievement gain per unit time spent (efficiency of learning), retention, attitude towards materials used and interaction effects of IQ, verbal PSAT, mathematical PSAT, grade level and sex. Assignment to treatment groups was not random.

While all three groups showed significant gains (posttest scores over pretest scores), the students using CSE (Group I) showed the greatest gains. Group I completed the unit 3.2 times faster than Group II and 8.3 times faster than Group III. Thus, CSE showed increased instructional efficiency over traditional laboratory style experiences. Of the variables studied, only sex and entry level performance knowledge as measured by the pretest significantly related to achievement in the unit.

With respect to retention, all groups showed significant gains six months later, although those students who used the previously filled in data sheets showed a signficant loss between the first and second posttests. Hence, use of film loops apparently did not make the data sheets memorable enough to compensate for the lack of psychomotor activ-

ity in the collection of data either by means of CSE or by actual manipulation of laboratory apparatus. This result conflicted with the results of the attitude survey which showed that the group using just the data sheets believed (wrongly) that the already filled in data sheets were more "efficient".

Lunetta's study suggests that (1) the computer terminal may act like a piece of manipulative laboratory apparatus with respect to the retention of concepts generated by data analysis, (2) that CSE is more efficient in terms of the time spent, and (3) that CSE can result in superior concept formation.

The role played by the film loops in providing a vicarious connection with actual laboratory apparatus as well as whether the same results could have been obtained without the intervention of the film loops are left unresolved. It does suggest, however, that a computer terminal (or any instructional method) which merely hands students the data will be less effective than a method which involves more active student participation.

A second study by Jones (1972) used CSE in both chemistry and physics in a Midwestern college-town high school. Eight physics classes (four PSSC and four Project Physics) and seven chemistry classes (four high ability and four low ability) involving two hundred fifty eight students and four teachers participated. In contrast to Lunetta's four sequential computer programs concentrated in the single area of Newton's second law, Jones wrote twenty-three discrete programs (thirteen in chemistry and ten in physics) of which only ten were used with any one group. The CSE programs miniced representative high school laboratory

experiments closely related to actual experiments in the existing program of the school.

The programs produced data tables which included small random errors. The data tables either were based on student selected values of the independent variables as limited by preprogrammed restrictions on the acceptable range (with the computer returning a single datum for a single student input value) or else they were completely computer generated and gave both dependent and independent variables after the student selected the initial circumstances.

Jones focused on whether CSE would influence students' attitudes towards (1) the subject, (2) laboratory work, (3) the computer as a laboratory aid, or (4) using a computer terminal. He looked for an interaction between sex, IQ, and GPA and attitudes or achievement. Finally, he asked whether student achievement was affected by using CSE. No attempt was made to determine the differential effects of his two styles of computer programming nor were verbal interactions studied.

Experimental and control groups were formed by random assignment from among students within the same class, and both groups "worked in the same laboratory at the same time" although teachers "discouraged the sharing of information between experimental and control groups. Students in the experimental group were encouraged to look at the equipment, but were not allowed to use it to take data. Students in the control group were not allowed to use computer generated data" (Jones, 1972, p. 30). All students were told they were participating in an experiment involving computer usage.

Attitudes (1) through (3) were measured using a pretest posttest

control group design while achievement and attitude (4) were measured by a posttest only control group design (Campbell and Stanley, 1963). Each of the ten separate achievement posttests was administered the day following the associated experiment. No cumulative examinations were given. There was no attempt at measuring either retention or learning efficiency as was done in Lunetta's (1972) study.

Jones concluded that CSE had no significant ($p > 0.05$) impact either on achievement or on attitudes towards either the subject or the laboratory work generally. However, students were significantly more positive towards computer use at the end than at the start, with males significantly more positive than females.

Jones noted (p. 63):

> . . . in some experiments it was difficult for students to visualize the meaning of the output data unless they had actually worked some with the particular type of equipment involved in that experiment. . . . the interaction of the experimental and control groups in the same laboratory . . . could influence results. The opportunity to watch students actually doing the same experiment undoubtably made the simulations much easier to comprehend. On the other hand, it was possible that those in the control group were able to pick up clues about the expected results from seeing computer simulated data tables.

It would appear from an examination of Jones' computer programs that they generated output which more nearly approximated the data sheets used with Lunetta's Group II (non-computer group). Lunetta's computer programs (listings in Lunetta, 1974) were much longer, and were more complex, interactive and conversational in character than Jones'.

The most economical interpretation seems to be that both Lunetta and Jones actually agree regarding achievement effects -- data tables qua data tables whether handed out by human beings or computer terminals

are not superior to traditional laboratory instructional methods. Rather, what these two studies suggest when combined is that more conversational CSE (i.e., CSE which more closely approximates a human being in interactions with students) or CSE coupled to sensory experiences which stimulate the integration of imagination and memory in retentive concept formation (either vicariously through an audiovisual presentation or kinesthetically through apparatus manipulation) may be superior to traditional methods.

This hypothesis was investigated by a subsequent study (Hughes, 1973) in which students using CSE with and without exposure to laboratory apparatus were compared with each other and with a traditional laboratory group. Hughes remarked (p. 140):

> . . . working with the laboratory equipment to obtain an understanding of the physical situation, coupled with the ease of using the computer to generate data, permitted students [who used both the computer and the equipment] to progress further (sic) in translating the results of the laboratory situations into meaningful conclusions.

In addition, with respect to learning efficiency, Hughes found (pp. 141-42):

> . . . those students exposed to the laboratory situation treat the computer as an extension of their laboratory work, performing enough trials to permit them to investigate the relationships completely [while] students having no exposure . . . perform an excessive number of trials [when using the computer alone].

In Hughes' two-factor experiment with repeated measures on one factor design (Winer, 1962), fifty-one students in two high school physics classes in Bexley, Ohio were randomly assigned to three treatment groups of seventeen students each. The students did four PSSC-style laboratory experiments (Newton's Second Law, Energy Changes in an Oscilla-

ting Spring, Coulomb's Law, and the Millikan Experiment) spread over four months. One group used CSE only (Group C), the second used CSE following a single trial manipulation of the actual laboratory apparatus (Group L-C), while the third used laboratory apparatus in the traditional manner (Group L).

Each of the three groups was aware of the activities of the other groups, and Hughes noted (p. 141):

> . . . there was interaction between the students in the various groups [which] may have acted to mask the effect of the treatments.

Two days were devoted to each experiment followed by a day of postlab discussion with all students participating regardless of treatment group. Student-teacher verbal interactions during the postlab discussion were not studied. The postlab was followed the next day by a test on the laboratory activity (KR_{20} = 0.82, = 0.65, = 0.75, = 0.92 respectively for each of the four tests). A cumulative examination (KR_{20} = 0.62) and an attitude survey were administered on the day after the final test.

Hughes compared (1) attainment of process skills, (2) acquisition of content, (3) number of trials performed, and (4) time involved for the three groups. He also compared attitudes towards CSE between Group C and Group L-C.

Those conclusions found to be significant (alpha $\leq$ 0.1) were, with respect to attainment of process skills, that Group L-C was better at developing experimental conclusions and that Group C performed more trials. No significant differences were observed for concept acquisition or time involved or with respect to attitudes towards CSE. This was in

contrast to the conclusions of Lunetta (1972) regarding achievement and Jones (1972) regarding attitudes.

It is possible that the fine-grained effects sought by Hughes were smeared to noise level by the exposure of students to the different treatments in the same laboratory at the same time, by the insertion of a mixed-group postlab discussion between treatment exposure and testing, and by the fact that, as with Jones (1972), an analysis of the computer programs Hughes wrote shows they merely generated realistic values of a dependent variable in response to student selected values of an independent variable.

If conversationality in programming is a desideratum for success in using CSE without teacher assistance to improve achievement and efficiency over traditional methods, then these three studies are complementary rather than contradictory since Lunetta's shows the superiority of conversational CSE while all three (Lunetta, 1972; Jones, 1972; and Hughes, 1973) indicate the absence of any superiority in non-conversational CSE.

All three support the contention that previous experience (vicarious or real) with experimental apparatus enhances learning with CSE. The apparent need for real or vicarious experiences with apparatus on the part of students, if achievement is to be higher with CSE than with traditional experimentation, casts doubt on the claim that CSE can substitute for experiments which cannot be performed in the high school laboratory because of safety, cost or physical impossibility.

As an aside, an indication of the transportability problem is shown by the fact that a different computer language was used by each of

the three investigators (Lunetta, 1972, 1974 - BASIC; Jones, 1972 - PL/1; Hughes, 1973 - FORTRAN).

In as much as conversational CSE appears superior to non-conversational CSE, one might ask whether a CAI computer dialogue is more effective with a supporting laboratory experience which is real than when the same computer dialogue is supported with a laboratory experience that is merely simulated. Could a common CAI experience be supported as easily by slides of the laboratory apparatus being manipulated as by requiring the students to operate actual apparatus?

Graham (1970) made such a comparison using a modified physics CAI lesson on magnetism and compared achievement between the CAI lesson using actual apparatus (manipulated by students during the lesson) and using simulated manipulation (by showing slides under computer control). Graham concluded that neither produced criterion performance by the students, and that the instructional efficiency was the same for each. Only the time required to set up the laboratory apparatus prior to student use was saved by the simulated version of the CAI lesson.

Hollen, Bunderson and Dunham (1971) found that, while mean achievement scores for CSE were twice as high as for traditional instruction, the differences were not significant although significant differences were observed in the time saved using CSE ($p < 0.005$). The addition of slides to the CSE presentation made no signficant difference in the effectiveness of CSE over traditional instruction, although the trend supported the use of the slides to provide a vicarious experience.

Ridney and Lutz (1975), however, report significantly higher recall of chemistry concepts for students using animated computer graphics

versus those given a computer generated verbal explanation. Students viewing graphics were higher on the recall of knowledge ($p < 0.02$), comprehension ($p < 0.1$), and application ($p < 0.02$).

Computer Assisted Lectures

Computer Assisted Lecturing (CAL) appears to be little used and not to have been evaluated, despite some calls in the literature for its employment (Bell and Moon, 1969; Meiser, 1976). There are few recorded uses of CAL (Corrin, 1966; Muller et al., 1973) and only two large scale installations for such use are known to the author (University of Texas, Austin, TX; Dartmouth College, Hanover, NH).

Although the effectiveness of CAL is not reported, it is suggested that CAI may be more effective with groups than with individuals (Gerrell, 1972) or, where equally effective, more efficient (Okey and Majer, 1975, 1976). It is also suggested that whenever the programming is sufficiently flexible to respond to students in an adaptive manner, rather than forcing them through a single sequence of content presentations, superior learning can result (Lahey et al., 1973). Thus an interactive lecture using a feedback loop that adapts the subsequent presentation of a computer simulated experiment may produce increases in learning efficiency and effectiveness.

In addition, no studies have been reported on student-teacher verbal interactions during computer assisted lectures.

Summary

With respect to the literature of CSE (and CAL), one might conclude:

1. CSE is least effective when merely generating data or verbal explanations

2. CSE is most effective when tied to some sensory experience on the part of the student and when the programming is conversational

3. Vicarious experiences may be as effective as actual apparatus manipulation in supporting CSE

4. CSE is at least as effective as traditional laboratory instruction, is more efficient, and, in some circumstances, may be more effective

5. CSE may be at least as effective in large group presentations as when it is used one-on-one

6. The impact of CSE use on student-teacher verbal interactions is unknown

If then, laboratory work is restricted to having as its goals concept formation and retention rather than acquisition of manipulative skills (which is certainly true of lecture demonstration experiments), the most efficient method would suggest itself as a combination of a teacher and a computer in a computer simulated demonstration experiment in which the strengths of both the human teacher (flexibility of response, perceptiveness, impedance matching, size of verbal repetoire) and the computer (speed and accuracy in computation, compression of space and time) would be linked to the students in a feedback loop.

It is further suggested that the effectiveness of the loop can be improved by providing concurrent sensory experiences for the students (either vicariously or through actual manipulation) which would make the experiment more concrete.

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